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Localized Innovation and Productivity Growth in Asia: An Intertemporal DEA Approach*

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Abstract
Recent contributions to growth theory stress the importance of localized innovation for the performance of more backward countries. In earlier papers, analyses by means of DEA techniques confirmed this intuition. In this paper, we extend this type of analysis by relaxing the macroeconomic viewpoint adopted until now. New databases on output, labour and capital input in the agricultural and manufacturing sector are developed for 40 countries. Using intertemporal DEA, it is found that changes in the global production frontier are localised at high levels of capital intensity. This result is stronger in agriculture than in manufacturing. Further, a decomposition of labour productivity growth in eight Asian countries for the period 1975-1992 into the effects of capital intensification, learning and innovation is made. The results suggest that there is a particular development path in which increases in capital intensity appear to be a prerequisite to benefit from international technology spillovers.

JEL: O14, O30, O40, O47.
Keywords: Economic growth; Productivity; Technological change; Data envelopment analysis; Asia.

* We would like to thank Donald Larson and associates at the World Bank for providing us with their cross-country database on investment and capital, and Gerard Ypma for data assistance. We benefited from comments and discussions with Tim Coelli, Rolf Färe and other participants at the Asia Conference on Efficiency and Productivity Growth, July 19-20, 2002 at the Academia Sinica, Taipei. Suggestions by Alessandro Nuvolari and other participants at the SOM/TEG Conference "The Empirical Implications of Technology-Based Growth Theories", August 26-27, 2002 at the University of Groningen are also gratefully acknowledged. The Dutch Organisation for Scientific Research NWO is gratefully acknowledged for financial support.
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1. Introduction

In recent years, a fruitful link has been established between the macroeconomic convergence debate and the production frontier literature. Empirical work based on the frontier approach, initiated by Färe *et al*. (1994), has yielded important new insights in addition to the more traditional growth accounting and cross-country regression studies. In first instance, the frontier approach was used to estimate total factor productivity (TFP) growth without the restrictive assumptions of a particular functional form for the production function and perfect competition. Additionally, TFP could be decomposed into changes in efficiency and technical change.[1] As such, the frontier approach can be seen as growth accounting "with a twist". More recently, patterns in labor productivity growth have been analyzed by means of frontier analysis. Using Penn World Tables data in a Data Envelopment Analysis (DEA), Kumar and Russell (2002) attributed convergence in the world economy to the effects of localized technological change (shifts in the world production frontier), technological catch-up (movements towards the frontier) and capital accumulation (movements along the frontier). They found that both growth and bipolar international divergence are primarily driven by capital deepening, which confirms the basic finding of Mankiw *et al*.'s (1992) cross-country regressions. In addition, the use of the frontier approach that allows for non-neutral technological change generated an important new insight. Global technological change was found to be decidedly non-neutral with no or moderate improvement in productivity at low capital/labor ratios and rapid growth at high levels of the capital/labor ratio. This suggests that countries that are far behind in terms of capital intensity will not benefit from global innovations, which is another possible cause for falling behind.

This finding potentially sheds new light on the growth experience of the East Asian economies. As has been stressed in growth accounting studies such as Young (1995), growth in Asia was mainly driven by a rapid increase in inputs through massive investment in human and physical capital, and once-and-for-all gains from increased labor participation and improved resource allocation between sectors. It is claimed that technical change played an insignificant role in this process (see also Kim and Lau, 1994). This finding has often been interpreted as a negative indication for further growth (Krugman, 1994). This interpretation is based on the traditional assumption of diminishing returns to capital accumulation. However, when global technological change mainly takes place at high levels of capital intensity, diminishing returns are far from inevitable. On the contrary, a period of high investment might be a pre-condition for being able to benefit from international technology spillovers in the long run. Only when a country has increased its capital-labor ratios to levels comparable to the countries in which most innovation takes place, it can start to benefit from global technological change.

In this paper we address two major shortcomings in the convergence frontier analysis literature to date: the high level of aggregation and the lack of a theoretical framework to interpret the results. So far, the level of aggregation is highly macroeconomic due to a lack of sectoral databases that cover both OECD and non-OECD countries. Bernard and Jones (1996) have shown that industry-specific analyses might be more appropriate for the study of convergence within OECD countries.

[1] See e.g. Perelman (1995) and Maudos *et al*. (2000) for studies of the performance of OECD countries. Krüger *et al*. (2000) and Chang and Luh (2000) focused specifically on the decomposition of Asian TFP growth. Lall *et al.* (2002) provide decompositions for Caribbean countries.

Convergence driven by technology diffusion typically occurs at the level of products or industries, rather than at the aggregate level. Hence, convergence at the industry level might not be reflected in macroeconomic statistics when countries differ in their industrial composition or experience different patterns of structural change. In this paper, global production frontiers are estimated for agriculture and manufacturing separately using DEA techniques. We use a new database on output, labor and capital input for 40 developing and developed countries to investigate whether sectoral patterns in the contribution of technological change, technological catch-up and capital deepening to labor productivity growth vary. If so, analyses based on aggregate data can be highly misleading. A novelty in our analysis is the use of an 'intertemporal' reference production set in determining the global frontiers by exploiting the panel nature of the data. For the calculation of the frontier at time *t*, not only data from period *t* is used, but also the history of data up to *t*. This ensures that technical regress cannot occur.
Secondly, we interpret the results in terms of a growth-theoretic framework in which spillovers and localized technological change play an important role in processes of growth and convergence. Instrumental in this respect is the appropriate technology theory of economic growth proposed by Basu and Weil (1998). We will argue that the capital intensification that characterised the growth patterns of many East Asian economies does not necessarily suffer from diminishing returns, because heavy investment may offer opportunities to benefit from relatively new technologies developed by Western countries.

The paper is organised as follows. In Section 2, the theoretical Basu and Weil (1998) model is discussed somewhat more deeply. It is shown how the results of standard DEA decomposition techniques can be interpreted in this framework. Section 3 is devoted to the intertemporal DEA approach to estimate global production frontiers. Section 4 describes the construction of the data set used to apply this methodology. In Section 5, we present the estimated global production frontiers for agriculture and manufacturing. Section 6 deals with the results from the decomposition analysis, with a particular emphasis on the productivity growth paths of agriculture and manufacturing sectors in East Asian countries. Section 7 concludes.

2. Decomposition of Labor Productivity Growth

Recently, Basu and Weil (1998) proposed a new theoretical model in which localised technological change plays an important role in explaining processes of growth, convergence and divergence in the world economy. They call a specific combination of production factors a "technology". In the simple case of two inputs (capital and labor), technologies are considered to be 'similar' if they are characterised by comparable capital to labor ratios. More advanced technologies have higher capital-labor ratios (capital intensities) and higher maximum labor productivity levels. A crucial element of this model is the assumption that innovation by leaders does not shift the production possibility frontier as a whole, but only a part in the neighbourhood of the specific combination of production factors currently in use by the leaders. For example, consider different technologies for transportation services: using a bicycle, using an electric train and using a high-speed magnetic train. Improvements in the productivity of the bicycle technology have very little effect on the productivity of the train technology. But improvements in magnetic high-speed train technology will have some spillovers to the electric train technology and hence improve its productivity as well. This process of 'localised innovation' was originally introduced by Atkinson and Stiglitz (1969). Because of localized innovation, history becomes important: a follower country can benefit from technology improvements made by a leader country in the past. If a country, for whatever reason, is not able to invest sufficient resources to adopt a capital intensity similar to that of the leaders, it will not benefit from changes in the frontier and fall behind. As a result of combining localized technological progress, appropriate technology conditions and differences in investment rates, convergence clubs can appear, the labor productivities of which grow at different rates.

The Basu and Weil model can be used to provide an interpretation of a well-known decomposition technique of productivity growth. Based on Malmquist distance functions, Färe *et al*. (1994) proposed a decomposition of total factor productivity growth into the effects of changes in technical efficiency (movements towards the frontier) and technological change (movements of the frontier). To decompose labor productivity growth rather that total factor productivity growth, the effects of changes in input combinations (capital-labor ratios) can be added. This is illustrated in Figure 1.

[Figure 1 about here]

Figure 1 contains two frontiers, $F(0)$ and $F(1)$, for periods 0 and 1, respectively, as well as two observations, indicated by *(0) and *(1). Labor productivity growth (y_1/y_0) is decomposed as follows:[2]

$$\frac{y_1}{y_0} = \left(\frac{y_1}{y_d} \cdot \frac{y_a}{y_0}\right) \cdot \left(\frac{y_c}{y_a} \cdot \frac{y_d}{y_b}\right)^{0.5} \cdot \left(\frac{y_b}{y_a} \cdot \frac{y_d}{y_c}\right)^{0.5}$$

or

$$\left(1+\hat{y}^T\right) = \left(1+\hat{y}^L\right) \cdot \left(1+\hat{y}^C\right) \cdot \left(1+\hat{y}^I\right) \qquad (1)$$

The first right hand side factor $\left(1+\hat{y}^L\right)$ measures the ratio between the vertical distance to the frontier in period 1 to that in period 0. A value of $\hat{y}^L$ larger than 0 thus indicates that the country under consideration has increased its level of technical efficiency. This can be interpreted as the result of "learning by doing" and indicates the extent to which a country has exhausted the potential of a particular technology. This potential is determined by innovative efforts of other countries which operated the same technology in the past, as argued in the Basu and Weil model. The second factor $\left(1+\hat{y}^C\right)$ is a Fisher index for vertical movements of the 'target' (the maximum attainable labor productivity for the country's technology) due to a horizontal shift of the country considered. When a country increases its capital intensity, $\hat{y}^C$ exceeds 0 indicating that a higher labor productivity level can be reached if it were to operate at the frontier. We call this movement 'creating potential', as it

[2] See Maudos *et al*. (2000) for a similar decomposition framework, based on Malmquist distance functions.

increases the potentially attainable labor productivity level of a country by increasing its inputs. The last factor $\left(1+\hat{y}^I\right)$ is also a Fisher index for vertical movements of the target and measures technological change. If the first two factors would equal 1, a positive value for $\hat{y}^I$ would mean that the country would have gained from innovation by leader countries. Hence labor productivity growth can be decomposed into three sources: ‘learning’, ‘creating potential’ and ‘innovation’.

3. Intertemporal Data Envelopment Analysis

In order to decompose labor productivity growth along the lines described above, a production frontier is needed. As discussed above, this frontier is the subset of all feasible techniques that attain the highest labor productivity levels for the particular technologies they correspond to. We use the Data Envelopment Analysis (DEA), because our focus on localized innovation requires as minimal assumptions on the shape of the frontier as possible.[3] DEA involves the use of linear programming methods to construct a piece-wise linear function over the data as follows. We assume constant returns to scale in capital and labor, which, by dividing through labor, allows us to reduce the problem to a one input (C/L), one output (Y/L) setting. The determination of the enveloping frontiers for one input (C/L) and one output (Y/L) as depicted in Figure 1 can be stated as a rather simple linear programming problem (see e.g. Coelli *et al*., 1998).[4] Assume the data on the inputs and outputs are known for each of *n* countries. For the *i*th country, they are represented by the scalars c_i and y_i respectively. Let c denote the (nx1)-input vector and y the (nx1)-output vector with observations for all countries. Then the problem (to be solved for i=1...n) can be stated as:

$$
\begin{aligned}
&\text{maximize } \theta_i \\
&\text{subject to:} \\
&-\theta_i y_i + \mathbf{y}'\boldsymbol{\lambda} \geq 0 \\
&c_i - \mathbf{c}'\boldsymbol{\lambda} \geq 0 \\
&n\mathbf{e}'\boldsymbol{\lambda} = 1 \\
&\lambda \geq 0
\end{aligned}
$$

Primes denote transposed vectors, e is an (nx1)-summation vector containing ones, λ is an (nx1)-vector of constants and θ_i are scalars ($1 \leq \theta_i < \infty$). The countries for which the envelopment problem yields θ_i=1 together determine the position and shape of the frontier. Thus, θ_i-1 is the proportional increase in output that could be achieved with the input quantities held constant and $1/\theta_i$ indicates the level of technical inefficiency.

In most DEA studies, the frontier at time *t* is calculated using data from period *t*. However, if panel data are available, the history of data up to *t* can also be included using the “intertemporal” reference

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[3] Although DEA was originally developed for firm-level analysis, it has frequently been used at the country level (see Färe *et al*., 1994, Perelman, 1995, and Kumar and Russell, 2002).

[4] For the actual calculation of the frontiers, we made use of the DEAP computer program developed by Tim Coelli (see Coelli, 1996).

production set (see Tulkens and Vanden Eeckaut, 1995, for a discussion). We have two important reasons to calculate the frontier at time *t* in this way. First, because the production frontier is constructed sequentially, it can never shift inward and hence technical regress cannot occur. The possibility of 'technological regress' seems awkward and hard to defend from a knowledge perspective on technology, as it would involve 'forgetting'. Second, as discussed above, a crucial element in the Basu and Weilmodel of appropriate technology is the possibility for countries to use knowledge that is generated by technology leaders in the past. Labor productivity levels of past technology leaders should be attainable for latecomers. Hence, we used all data up to and including period *t* in our construction of the frontier at time *t*.[5]

A possible disadvantage of the intertemporal approach is the dimensionality problem. It has been pointed out that technical efficiency scores of a single observation estimated using DEA will tend to decrease as the number of observations included in the DEA application increases. This is because, as the number of observations increases, the chance of encountering points close to the true production frontier increases, and therefore the frontier constructed by DEA approaches the true frontier asymptotically as the number of observations increases.[6] However, in this particular application the dimensionality problem does not arise as the number of countries is constant over time. A related problem however is that not all input-output combinations realized in the past have been observed as the data set starts only in 1970. It is possible that frontier techniques observed for the first years of the analysis are dominated by unobserved combinations in the past. Hence part of what is interpreted as frontier movements is in fact improvement in technical efficiency relative to these unobserved combinations. To accommodate this potential problem, we limit the decomposition analysis to the time span that starts five years after the first observations available to us.

4. Data sources

In our study, we use data on one type of output (GDP) and two types of inputs (labor and capital) for two sectors, agriculture and manufacturing. Annual data has been collected for the period from 1970 to 1992 and covers 40 countries. These include 17 OECD countries, 23 mid-income countries and 10 low-income countries (see appendix 1 for full list of countries). As no coherent and comprehensive dataset, such as the Penn World Tables for aggregate economies, is available, a collection of sources has been used. Gross Domestic Product for agriculture and manufacturing in constant 1990 national prices were derived from various issues of the United Nations, *National Account Statistics* and OECD *National Accounts* combined with national data collected in the Sectoral database of the Groningen Growth and Development Centre (GGDC). To make cross-country comparisons possible, average market exchange rates for 1990 from the IMF, *International Finance Statistics*, were used to convert the data into 1990 US dollars.[7]

Agricultural labor data was taken from a variety of sources. The main source for OECD and most Asian countries was national data collected in the *GGCD Sectoral Database*, complemented with

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5 Surprisingly, this approach is rarely used in empirical studies, although it has been developed for time series in linear programming tests of the efficiency hypothesis by Diewert (1980) and in the sequential Full Disposable Hull approach by Tulkens (1986).

6 See Zhang and Bartels (1998) for Monte Carlo and empirical studies of this phenomenon.

OECD, *Labor Force Statistics*. For other non-OECD countries, data from the FAO database was used. This data is based on population censuses and interpolated by the FAO on the basis of agricultural population growth rates. For manufacturing employment, national data collected in the GGDC *ICOP industry database*[8] was used, complemented with OECD, *Labor Force Statistics* and data from the ILO, *Labourstat* database. It was ensured that all employment figures refer to all workers engaged, not only employees.[9]

Capital stocks have been taken from Larson *et al*. (2000). The main novelty in their dataset is the careful calculation of the agricultural capital stock. Their main aim was to construct internationally comparable agricultural capital stocks based on investment data from the national accounts. Although according to the United Nation's accounting principles, fixed capital investment should include livestock and treestock, they found that this is not the case for many countries. Hence alongside fixed investment, separate series for investment in livestock and treestock were estimated and added to the fixed capital stock.[10] Capital stocks were built using the perpetual inventory method.[11] Market exchange rates were used to convert stocks into comparable US dollar values. A similar approach has been used for the manufacturing fixed capital stock.

5. Global Frontiers in Agriculture and Manufacturing

In Table 1, we provide an overview of the countries on the global production frontiers in 1975 and 1992, in both manufacturing and in agriculture. The table gives the capital-labour ratios (K/L) and labour productivity levels (Y/L) of those countries which constitute the frontier in 1975 or 1992. Both the country name and the year for which the frontier observation was made are given. As is clear from the table, the frontiers in 1975 and 1992 do not solely consist of observations made in the same year. This is due to our use of the intertemporal DEA approach. In fact, for agriculture none of the countries in 1992 is on the frontier in 1992. And in manufacturing , Denmark 1984, for example, is still on the frontier in 1992. This means that the labor productivity level generated in Denmark in 1984 has not been surpassed by any other country operating a capital-labor ratio (or technology in the sense of Basu and Weil) similar to Denmark in 1984. In 1992, Greece, South Korea and Taiwan operated at comparable capital intensity levels as Denmark in 1984, but with much lower labor productivity levels. As a consequence, Denmark 1984 still remains at the frontier for that particular technology.

[Table 1 about here]

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7 End-of-year and/or official rates were used if average market rates were not available.

8 See http://www.eco.rug.nl/ggdc/index-dseries.html for downloadable series of the GGDC sectoral and industry databases, see also Timmer (2000) for series on Asia.

9 This is important, as especially in less developed countries a large part of the manufacturing labour force consists of own-account and household workers. Excluding these workers would overstate relative labour productivity levels in these countries.

10 This procedure might lead to overestimation of the capital stock in some countries as livestock and treestock were included already. But Larson *et al*. (2000) judged that this situation was much less frequent.

11 A general formulation of the age-efficiency pattern was used, which comes close to geometric deprecation at a rate of 0.06 (Larson *et al*., 2000, p. 383).

In Figure 2, the frontiers for 1992 are shown together with the observations for that year. As implied by our application of standard DEA techniques the frontiers are convex, as more sophisticated, capital-intensive technologies can yield higher labor productivity levels. One can see that the use of an intertemporal reference set rather than a contemporaneous one makes a difference, not only in theory, but also in practice. Some countries that would be on the contemporaneous frontier, and hence judged to be efficient, are now considered to be inefficient.

Comparing agriculture with manufacturing shows some interesting differences. First of all, the range of capital intensities in agriculture is much wider than in manufacturing. In agriculture, a clear gap between the capital intensities (technologies) used in developed and developing countries can be identified (see also the appendix table). Secondly, the maximum attainable labor productivity at a given capital intensity is much higher in manufacturing than in agriculture.

[Figure 2 about here]

In Figure 3, we provide a sketch of the progress that was made at the frontier over the past decades. Based on the intertemporal frontiers for 1975, 1980, 1985 and 1992, the labor productivity levels attainable with a particular capital/labor ratio are given, with the level in 1975 indexed at 100. It shows for example that in agriculture, the maximum attainable labor productivity level for a capital intensity of 120,000 US$ increased more than 30 percent between 1975 and 1985, and more than 50 percent between 1975 and 1992. Figure 3 shows that global innovation in both agriculture and manufacturing is highly localized and skewed towards the higher capital intensities. This stresses the importance of localized innovation as an additional driver of divergence in the world economy, confirming the finding at the aggregate level of Kumar and Russell (2001) and Los and Timmer (2001).

Figure 3 also shows that most innovation has taken place between 1980 and 1992, irrespective of the sector that is considered. This innovation includes the development of new technologies with high capital-intensities hitherto unexplored, as well as improvements in already existing technologies. In agriculture, innovation has only taken place in the advanced, capital-intensive, technologies. The higher the intensity level, the bigger the improvement in labor productivity levels appears to be. In manufacturing, this pattern is less pronounced, especially in the period until 1985. In the latest period strong innovation took place at the high-end technologies. In the period 1975-1985 considerable innovation took place in the mid-range technologies, which covers technologies of about 30,000 US$ per worker and more. Note however, that in 1992, 18 out of the 40 countries still operated technologies below this level, indicating that they did not benefit from the progress being made at the frontier.

To summarize, the intertemporal approach to identify frontiers offers empirical support for the Basu and Weil-view of the world in which technological progress is highly localized, benefiting mainly the more advanced countries. In the next section, the focus will be on the implications of this characteristic of the global innovation process for the growth performance in Asia.

[Figure 3 about here]

6. Decomposition of Asian Growth Patterns

Using the estimated frontiers it is possible to calculate the distance to the frontier of each country in a particular point of time. In Table 2 these efficiency scores for 8 Asian countries are given, together with the scores for France, UK and USA for reference. When the level is 1, the country is efficient and operates on the frontier. The lower the score, the bigger the gap to the frontier. India and Pakistan are two countries where the efficiency scores are particularly low in both agriculture and manufacturing (well below 40 % throughout the period 1975-1992). In South Korea and Taiwan, relative efficiency is relatively high in agriculture, Korea operating near the frontier in 1975 and again in 1985. Efficiency in manufacturing on the other hand was much lower at 40 and 52 per cent respectively in 1992. For the other countries the pattern is reversed, as manufacturing activities are much more efficient than agriculture. This is particularly true for Japan, but also for the Philippines and Sri Lanka.

[Table 2 about here]

However, having a high efficiency score is not necessarily a positive sign for future labor productivity growth as it indicates that the potential for future growth on the basis of learning is limited. Learning as a source of growth ceases once the frontier has been reached. This is especially true when this particular country is "stuck" at a part of the frontier where no innovation takes place. To avoid this lock-in in stagnant technologies, increases in capital intensity are needed. A sector that increases its capital intensity creates a higher potential to benefit from learning spillovers in the future, as maximum attainable labor productivity levels increase with increasing capital intensity. Moreover, it may enter the range of capital intensities in which innovations shift the frontier upwards. This might ensure that marginal returns to investment do not diminish, but remain constant or even increase. The specific outcome depends on the size of the productivity enhancing effects of the innovation process in the leading countries and on the ability of more backward countries to capitalize on the increased potential for learning. The decomposition of labor productivity growth proposed in equation (1) can shed some light on this issue.

[Table 3 about here]

The first columns of the panels in Table 3 show the average annual labor productivity growth rates for the period 1975-1992 for agriculture and manufacturing respectively. This growth rate is decomposed according to equation (1) into the effects of learning, spillover potential creation and innovation. Figures are given for 8 Asian countries with France, United Kingdom and USA as points of reference.

In panel A the results for agriculture are given. In India, the Philippines and Sri Lanka average annual labor productivity growth rates were less than 1 per cent, and mainly due to what can be called "fishing out". Starting from a low level of technical efficiency labor productivity in the sector increased only on the basis of learning. This path was possible as efficiency levels were very low in 1975 (see Table 2). Indonesia managed to follow a "creating with learning" path by simultaneously raising its capital intensity and learning levels. Consequently it had a higher growth rate of labour productivity (2.2 % on average). Labor productivity growth rates in Japan and particularly in Korea and Taiwan were much higher. This was overridingly due to a shift towards more sophisticated technologies, and not due to learning from appropriate technology spillovers. This “creating potential” path was the only way to maintain potential for learning, as efficiency was already high in 1975 as indicated in Table 2. Whereas Taiwan combined creating with a minimum amount of learning, Korea clearly followed a path of creating without learning. In contrast to Korea and Taiwan, which were still using very labor intensive technologies, Japan also could benefit from innovation at the frontier, accounting for more than a third of its labor productivity growth. More advanced countries such as the UK and especially the USA followed an innovation driven path where innovation accounts for 50 % or more of labor productivity growth .

In manufacturing, the role of “innovation” in Asian growth is more pronounced than in agriculture, due to global frontier shifts in the mid-range technologies pointed at in the previous section. Results for manufacturing are given in panel B of Table 3. In addition to this Table, Figure 4 provides a graphical presentation of the decomposition results through time. The righthand side graphs show for a limited number of countries changes in the actual labour productivity levels and its sources: learning, creating and innovation. The left hand side graphs show the development of actual labor productivity and the movement of the target, that is, the maximum labor productivity level attainable as indicated by the frontier.

Sri Lanka and the Philippines had low levels of labor productivity growth during the period 1975-1992 and followed a path of “backtracking” by decreasing their capital intensity levels. Productivity growth in Indian manufacturing was mediocre at 2.7 % annually and a clear case of “fishing out” as indicated by the large contribution of learning. South Korea and Taiwan had high growth rates of labor productivity due to “creating potential”. However, as in agriculture, for Korea creating took place without learning. Technical efficiency levels in Korea declined rapidly, whereas they remained constant in Taiwan (see also Figure 4). The same is true, at a much lower level, for Pakistan. In Indonesia manufacturing labour productivity grew very fast at more than 6 % annually driven by both capital intensification and learning. In contrast to the other Asian countries, Japan mainly grew on the basis of learning and especially innovation. It was “fishing out” technologies were innovations took place. France and the US grew mainly on the basis of “innovation”. The potential for learning was small as labor productivity levels in 1975 were already close to those at the frontier (see Table 2). UK growth was mainly based on capital intensification, but as it entered the capital intensity ranges in which most innovations took place, a major contribution of innovation was found as well.

These findings suggest a sequence in which countries first created opportunities for labor productivity growth by rapidly increasing capital intensities. Next, learning through the effective assimilation of new, appropriate technologies gained in importance, to be followed by profiting from developments at the global technology frontier. Japan’s manufacturing sector seems to have had almost completed this sequence in 1992. The East Asian miracle economies, South Korea and Taiwan, are still halfway this process. The potential for catch up solely by means of learning was very large and even growing at the end of the 1980s, as can be inferred from the growing gaps between actual and target labor productivity levels in Figure 4. Consequently, the potential for further productivity growth is still substantial, in particular because this potential was created by the strong capital intensification. The next challenge for the East Asian growth miracles is to capitalize on this potential.

7. Concluding Remarks

This paper provides an intertemporal DEA analysis of labor productivity growth in the agricultural and manufacturing sectors of 40 countries in the period from 1975 to 1992, with special attention for the Asian growth experience. This analysis offered three new insights. First, the capital intensities that characterize technologies vary across a much wider range in agriculture than in manufacturing. In addition, for each and every capital intensity, maximum labor productivity levels are (much) higher in manufacturing than in agriculture. Because the shares of agriculture in aggregate employment are generally higher in countries with capital-extensive agriculture, this results strengthens the intuition that productivity growth patterns should be studied at a level as disaggregated as possible.

Second, we found that technological progress is clearly localized in both agriculture and manufacturing. This may be seen as evidence in favor of theories of economic growth introduced by Atkinson and Stiglitz (1969) and Basu and Weil (1998). It should be noted, however, that the localized nature of innovation is not uniform across sectors. In agriculture, innovation only took place within the high capital intensity segment of technologies, whereas in manufacturing some countries that operated low or medium capital intensity technologies appeared to have shifted the frontier outwards, too. As a results, innovation was not a source of labour productivity growth in agriculture for any Asian country, except Japan. Only Japan produced with a sufficiently high capital intensity to benefit from advances in Western countries. In manufacturing, innovation had a bigger impact on labour productivity growth in Asia than in agriculture.

Third, the decomposition results of labour productivity growth suggest a sequencing of the growth process in Asia in which increases in capital intensity appear to be a prerequisite to benefit from international technology spillovers. The growth pattern in countries like the Philippines, Sri Lanka and to a lesser extent India, is characterised by a lack of capital intensification. Given the fact that they operated at low levels of capital intensity where no innovation took place, future growth is only possible on the basis of learning, that is, improving their technical efficiency. However, this source of growth is exhausted once the frontier is approached. Indonesia on the other hand started to increase its capital-labour ratio, allowing it to benefit from innovations at the frontier (in manufacturing). In South Korea and Taiwan, this process of technological upgrading was pushed much harder, generating much higher labour productivity growth than in Indonesia. They followed the lead of Japan where capital intensification drove growth in the 1970s, which enabled Japan to benefit much more from innovation in the 1980s than the Asian countries.

The results must been seen as a first attempt to shed new light on the role of spillovers in productivity growth in Asia. The dataset needs improvement in various respects. Most importantly, purchasing power parities are needed to make output and capital stock values comparable across countries. As is well known, exchange rates do not adequately reflect relative prices in countries and can be highly misleading if used to convert national currencies into a common denominator. For the purpose of comparisons by sector, industry-of-origin PPPs are to be preferred.[12] These will be used in a later stage

[12] See e.g. Timmer (2000) for PPPs for the manufacturing sector in a number of Asian countries.

of this research. Next, further research is needed to come up with better capital stock estimates. Especially in the case of agriculture, land should be considered as an additional input, or as part of the fixed capital stock.[13] Also human capital is an important input which should be taken into account.

On a more analytical level, the results in this paper can be useful in an attempt to reconcile findings at the sectoral level with results at the aggregate. For example, the link between changes in efficiency scores within sectors and at the aggregate are still poorly understood. Shifts in the distribution of capital and labour across the sectors will play an important role in this respect but have not been studied yet.

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[13] A good example is Rao and Coelli (1999) who provide a DEA analysis of the agricultural sector using two outputs (crops and livestock output) and 5 inputs (physical quantities of land, tractors, labour, fertiliser and livestock) for 97 countries over the period 1980-1995.

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Figure 1 : Decomposition of labor productivity growth

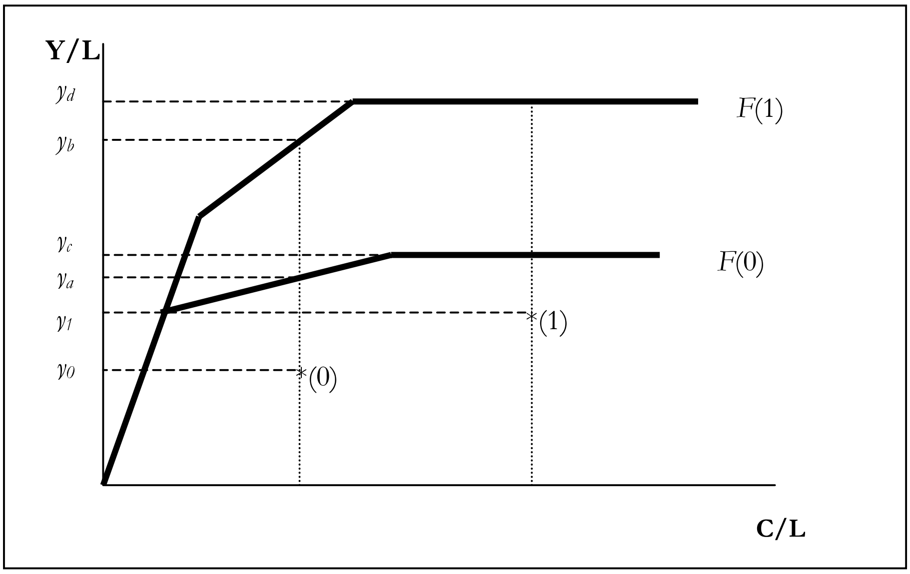
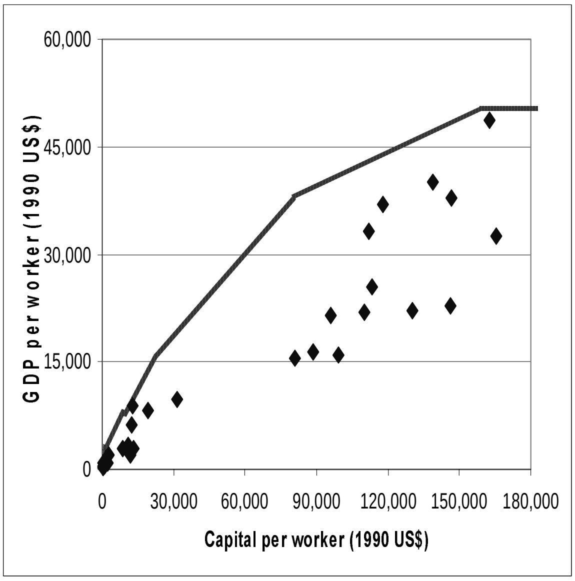


Figure 2 Observations and Frontiers in 1992

(a) Agriculture



(b) Manufacturing

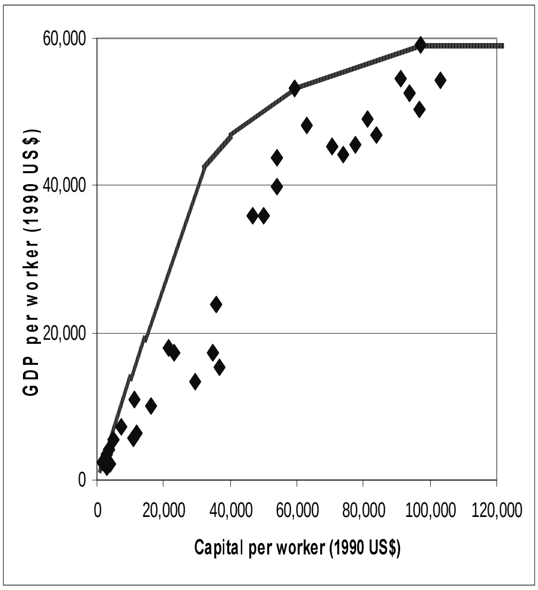
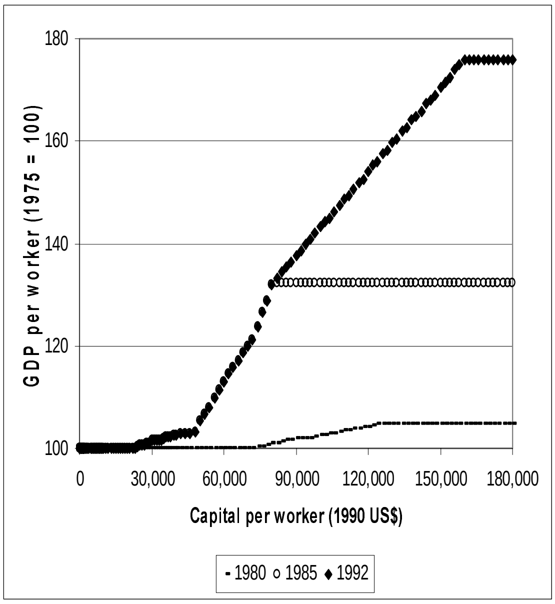


Figure 3 Development of Frontiers , 1975-1992 (1975 = 100)

(a) Agriculture



(b) Manufacturing

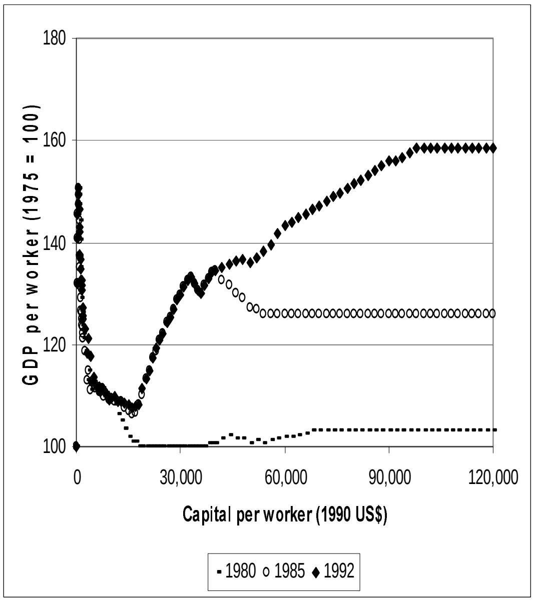
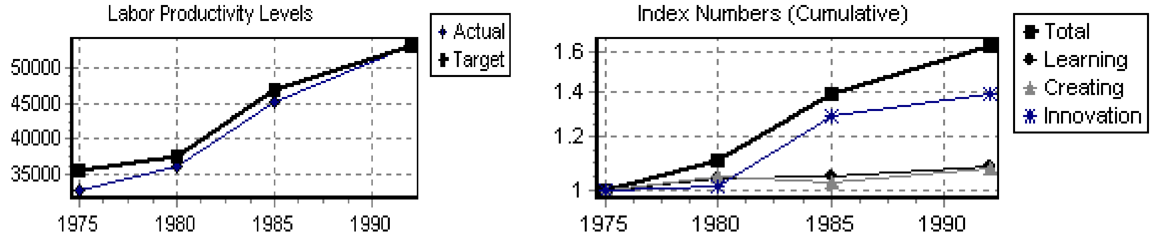
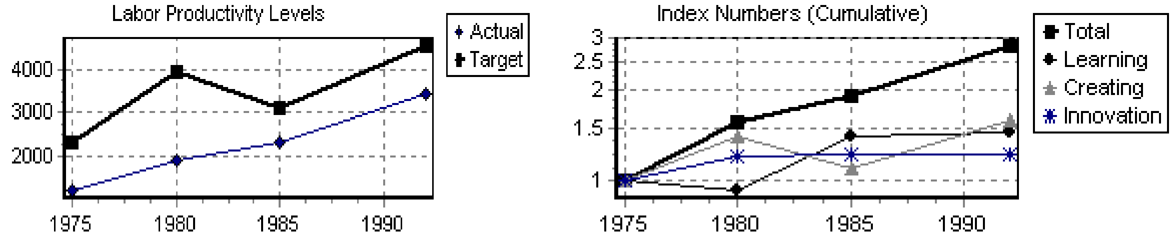


Figure 4 Movement of target and actual labor productivity levels, and decomposition of actual labor productivity growth, manufacturing, 1975-1992

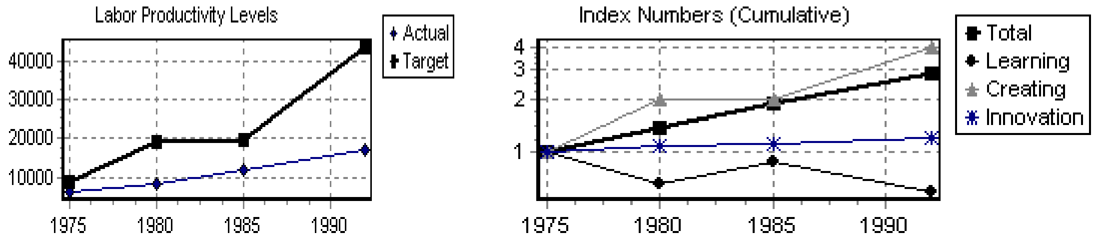
(a) USA



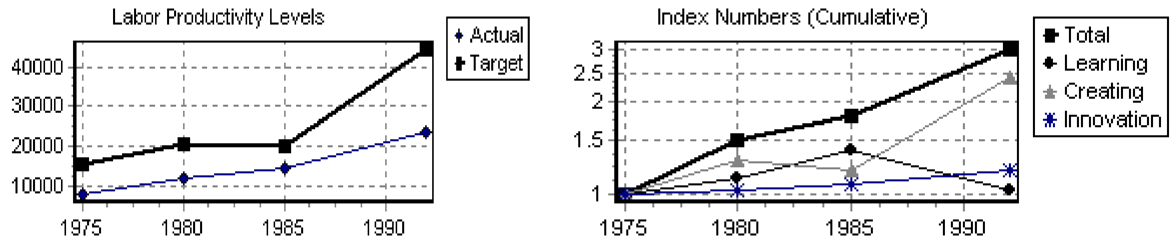
(b) Indonesia



(c) South Korea



(d) Taiwan



(e) Japan

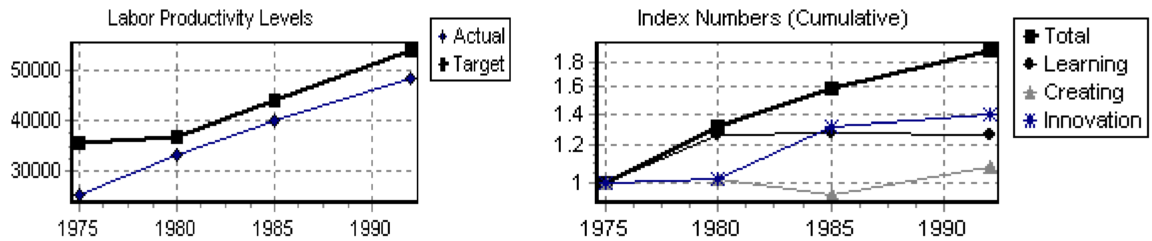


Table 1 Input-output combinations on frontier, 1975 and 1992

(A) Agriculture

Frontier in 1975				Frontier in 1992			
		K/L (a)	Y/L (b)			K/L (a)	Y/L (b)
Indonesia	1970	364	406	Indonesia	1970	364	406
Korea	1970	961	2,792	Korea	1970	961	2,792
Korea	1971	1,019	2,940	Korea	1971	1,019	2,940
Japan	1970	9,310	7,784	Japan	1970	9,310	7,784
Finland	1970	22,805	15,567	Finland	1970	22,805	15,567
Sweden	1971	47,999	24,591	Sweden	1985	80,307	37,991
Sweden	1974	72,632	28,771	Sweden	1990	159,187	50,421

(B) Manufacturing

Frontier in 1975				Frontier in 1992			
		K/L (a)	Y/L (b)			K/L (a)	Y/L (b)
Indonesia	1971	818	847	Sri Lanka	1978	711	1,317
Sri Lanka	1975	1,133	1,369	Indonesia	1988	1,585	2,605
Philippines	1971	3,021	3,805	Peru	1978	9,985	13,689
UK	1970	17,233	21,445	Peru	1987	14,093	18,987
US	1973	35,571	33,845	Denmark	1984	32,563	42,286
Norway	1973	47,019	36,157	Belgium	1985	40,096	46,898
Norway	1974	53,469	37,307	US	1992	59,257	53,222
				Finland	1992	97,263	59,111

Notes: (a) Gross fixed capital stock per worker (in 1990 US$)
(b) GDP per worker (in 1990 US$)

Table 2 Efficiency Levels in Agriculture and Manufacturing, 1975-1992

	Agriculture				Manufacturing			
	1975	1980	1985	1992	1975	1980	1985	1992
Asian Countries								
India	0.13	0.12	0.13	0.22	0.25	0.22	0.28	0.37
Indonesia	0.26	0.24	0.41	0.27	0.53	0.49	0.75	0.76
Japan	0.70	0.50	0.61	0.42	0.71	0.90	0.91	0.90
Korea	0.96	0.69	0.97	0.60	0.69	0.44	0.60	0.40
Pakistan	0.11	0.12	0.14	0.17	0.32	0.21	0.34	0.39
Philippines	0.24	0.29	0.39	0.52	0.84	0.74	0.75	0.82
Sri Lanka	0.13	0.17	0.26	0.40	1	0.76	0.74	0.86[a]
Taiwan, China	0.66	0.75	0.85	0.66	0.52	0.59	0.73	0.54
France	0.47	0.60	0.80	0.77	0.85	1	0.92	0.94
UK	0.59	0.71	0.79	0.78	0.85	0.68	0.86	0.85
USA	0.72	0.69	0.75	0.88	0.92	0.96	0.96	1

Note: (a) figure for 1990
Source: Efficiency scores based on intertemporal DEA, see main text

Table 3 Decomposition of labor productivity growth, 1975-1992

(a) Agriculture

	Average annual labor productivity growth	Explained by		
		Learning	Creating potential	Inno vation
India	0.38	3.42	-3.04	0.00
Indonesia	2.20	0.35	1.85	0.00
Japan	2.46	-3.03	4.55	0.91
Korea	5.40	-2.75	8.15	0.00
Pakistan	1.92	2.50	-0.58	0.00
Philippines	0.81	4.63	-3.82	0.00
Sri Lanka	0.89	6.43	-5.54	0.00
Taiwan	4.51	0.05	4.46	0.00
France	5.43	2.88	0.87	1.68
UK	3.51	1.68	0.04	1.76
USA	3.32	1.16	-0.20	2.36

(B) Manufacturing

	Average annual labor productivity growth	Explained by		
		Learning	Creating potential	Inno vation
India	2.67	2.38	-0.67	0.96
Indonesia	6.11	2.20	2.69	1.22
Japan	3.82	1.41	0.46	1.99
Korea	6.06	-3.21	8.18	1.09
Pakistan	5.61	1.12	3.42	1.07
Philippines	-0.51	-0.08	-1.29	0.85
Sri Lanka [a]	0.95	-0.98	-0.50	2.43
Taiwan	6.43	0.19	5.21	1.03
France	3.17	0.54	0.25	2.35
UK	3.54	0.04	1.88	1.63
USA	2.88	0.49	0.43	1.93

Note: (a) Sri Lanka covers period 1975-1990.
Source: for sources and decomposition, see main text.

Appendix Table 1

Capital per worker (K/L) and GDP per worker (Y/L) in 1975 and 1992 (in 1990 US$)

	Agriculture				Manufacturing			
	1975		1992		1975		1992	
	K/L	Y/L	K/L	Y/L	K/L	Y/L	K/L	Y/L
Australia	141,615	18,989	113,350	25,474	46,863	25,862	46,710	35,817
Austria	63,303	8,261	99,086	15,844	44,749	26,110	81,092	49,068
Belgium	112,634	17,600	138,767	40,050	60,349	26,304	103,119	54,398
Canada	121,180	19,687	109,952	21,922	50,193	29,529	77,440	45,593
Chile	12,660	1,666	13,218	2,833	15,372	4,510	5,006	5,502
Colombia	5,268	1,154	n.a.	1,832	9,576	9,344	7,309	7,270
Costa Rica	16,248	2,426	10,789	3,213	n.a.	n.a.	12,070	6,332
Cyprus	7,924	2,829	31,601	9,836	22,408	10,925	23,221	17,248
Czechoslovakia	18,787	2,873	n.a.	n.a.	16,677	6,242	n.a.	n.a.
Denmark	91,294	12,210	165,330	32,560	43,262	30,423	73,917	44,310
Egypt	1,085	708	n.a.	n.a.	8,234	2,248	n.a.	n.a.
Finland	52,218	18,819	117,683	36,916	52,415	27,467	97,263	59,111
France	67,110	13,167	112,076	33,141	59,807	31,790	91,217	54,461
Germany	n.a.	10,215	n.a.	27,706	42,970	34,848	67,663	48,040
Greece	11,106	5,906	12,839	8,904	n.a.	n.a.	29,589	13,328
Honduras	5,450	1,135	2,727	1,945	n.a.	4,370	n.a.	3,927
India	1,264	384	720	410	3,334	1,048	2,954	1,651
Indonesia	719	467	889	679	1,872	1,220	3,048	3,447
Israel	63,961	20,042	96,019	21,563	30,397	24,823	54,088	39,875
Italy	37,053	9,785	130,126	22,211	32,557	22,065	70,543	45,360
Jamaica	3,145	976	1,883	1,135	19,115	12,101	n.a.	n.a.
Japan	22,679	10,797	88,530	16,398	44,371	25,182	62,971	48,235
Korea	1,735	3,229	19,057	8,090	7,202	6,166	34,864	17,283
Netherlands	92,583	19,083	146,787	37,779	56,623	27,025	84,001	46,866
New Zealand	129,784	13,747	80,975	15,431	33,720	23,392	50,192	35,857
Norway	83,040	15,708	146,284	22,784	62,567	37,282	96,726	50,330
Pakistan	1,611	358	1,087	496	2,203	884	4,087	2,295
Peru	3,470	1,011	2,476	927	15,763	15,175	21,413	18,008
Philippines	1,312	740	669	849	4,439	4,647	3,528	4,261
Poland	9,931	773	n.a.	n.a.	15,590	6,451	n.a.	n.a.
South Africa	10,604	1,457	11,773	2,020	25,665	13,460	36,642	15,273
Sri Lanka	1,796	456	594	530	1,133	1,369	1,059[a]	1,579[a]
Sweden	84,462	27,090	162,657	48,788	59,562	35,443	93,728	52,619
Taiwan, China	3,568	2,905	12,256	6,257	12,310	7,994	35,892	23,857
Tanzania	1,002	134	585	182	n.a.	2,442	n.a.	637
Tunisia	6,352	1,630	8,815	2,803	7,310	3,464	10,987	5,606
Turkey	3,502	1,819	2,657	1,955	23,167	12,699	11,291	10,908
UK	83,461	16,910	87,844	30,714	27,421	24,039	54,132	43,894
Uruguay	31,696	4,101	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
USA	121,507	20,718	102,752	36,408	43,788	32,619	59,257	53,222
Venezuela	22,165	2,327	n.a.	3,137	33,271	11,999	16,216	10,024

Note (a): figures for 1990